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User Profiling for Energy Optimisation in Mobile Cloud Computing

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Abstract

Both mobile and cloud computing are two areas which are rapidly expanding in terms of use case and functionality.Both mobile and cloud computing are two areas which are rapidly expanding in terms of use case and functionality. This paper reviews current work in energy consumption of mobile cloud computing and then proposes a system whereby user applications may be profiled for their resource consumption locally and then if augmentation is required, they may negotiate with an external cloud for optimum energy consumption. Such a system is particularly useful for cloudlets which contain constrained resources so may need to choose between a number of clients. Whilst mobile computing enables a variety of feature rich functionality for users in a non-fixed location, cloud computing is revolutionising the way in which computing resources are being provisioned, used and optimised for both service providers and end users. These two fields are being combined in order to provide greater functionality for mobile devices in a number of different ways. Augmentation of mobile resources from the cloud has been shown as one way in which the energy consumption and power of mobile devices may be considerably enhanced. However, due to the resource constrained nature of the devices, in particular their power source and communication interfaces, there is often a fine line where offloading of these resources is economical.

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1. Introduction

Whilst mobile computing is arguably becoming the end-user device of choice, particularly for remaining connected to external services, Cloud computing is arguably becoming the foremost computing service delivery platform. It is a form of utility computing, whereby computing resources are sold as an on demand, scalable, pay-as-you-go resource provided to the end-user by a Cloud Service Provider (CSP). Clouds are typically the combination of a number of geographically dispersed data-centres which provide (seemingly) unlimited scalable storage and processing resources. Resources are typically provisioned and delivered via a connection to the internet.

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In contrast, mobile computing is a human-computer-interaction paradigm, in which a user interacts with a computer device in a non-fixed setting. This has revolutionised computing access on a grand scale by enabling these resources to be harnessed without constraints upon mobility or time. The primary downside to mobile computing is the constrained resources (processing, memory etc.) resulting from a limited power source (battery) and form factor. This brings about a number of restrictions upon the device, in particular its limited power source which ensures that hardware resources must be used with consideration for power consumption. Mobile Cloud Computing (MCC) is the combination of the Mobile Computing and Cloud Computing paradigms. This can culminate in a number of forms, which will be discussed further on in the paper.

Much research has been conducted in energy consumption on mobile devices as the functionality of the device it as its greatest when its power consumption is optimised. In some work, wireless networking devices have been shown to be one of the largest consumers of energy on a mobile device as well as varying in financial expense in a number of use-cases. In addition, processing capabilities on mobile devices can rival desktop machines for certain functionality. Therefore, in order to truly realise the effect of connectivity between mobile devices and cloud computing environments it is necessary to determine if they are being leveraged effectively in order to economise energy consumption.

The rest of this paper is as follows: Section 2 provides background information on MCC whilst Section 3 introduces energy consumption within the context of MCC. The specification and design for a proposed software profiler with augmentation negotiator, which will enhance and economise on energy usage for MCC is presented in section 4. Finally, section 6 presents the conclusion.

2. Mobile Cloud Computing

Mobile Cloud Computing is the inevitable result of the fusion between three computing fields: Mobile Computing, Cloud Computing and networking. This fusion of fields may actually be found in a number of different forms[1]. Enabling mobile devices to access cloud resources, allowing offloading of resources onto cloud platforms and building cloud platforms from mobile devices. Each one of these models comes coupled with different challenges and features but on the fundamental level they all combine the aforementioned fields but with a different purpose and result.

2.0.1. Cloud Resource Access

The first mobile cloud computing usage model is arguably the most common; as it merely describes the access of cloud resources by mobile devices. Mobile devices (such as smartphones) are designed to have (mostly) continuous access to the internet and therefore, cloud computing. This may take the form of low bandwidth applications such as e-mail and general purpose web surfing (social media etc.) or more high bandwidth applications such as video streaming and online gaming. This requirement for continuous access inherits issues from mobile computing related to quality and consistency of network connectivity. Further issues are also brought forward from the heterogeneous nature of the devices such as the varying software and hardware requirements. To the developers of these applications, many of these issues may be solved by an appropriate middleware[2], Service Oriented Architecture (SOA) such as those widely established for the web, or virtualisation[3].

2.0.2. Ad-hoc Mobile Clouds

In addition to accessing resources of remote clouds, mobile devices may also be employed as the resource providing nodes which compose the cloud architectures. This is accomplished in order to provide the majority of the cloud features such as distributed and scalable processing and storage; within a localised environment. This has the primary advantage of excluding usage of WAN links which are costly(in terms of energy) and not particularly reliable or stable. Despite the constrained nature of the devices, it is argued that the increase in processing power of these devices year on year, as well the savings in energy by using local, less power consuming, protocols would reap some benefits over offloading to a traditional cloud[4,5]. However, a number of issues are still prevalent with this type of cloud, including inherited networking characteristics (mobility, open links etc.) and challenges related to job allocation and assignment[6].

2.0.3. Resource Offloading

The method of enabling mobile devices to offload computation or storage to the cloud. This has the potential to provide the mobile devices with increased functionality that they might otherwise be unable to deliver, due to their constrained power and hardware resources. Remote resource augmentation has the potential to enable a variety of greater functionality such as increased graphical capabilities such as with high end games and increased processing capabilities such as with security analysis. It also has the potential to increase the battery life of the device through minimising component usage. Resources may be gathered from traditional CSPs, Cloudlets[7,8,9] or Mobile Ad-Hoc Clouds. Various techniques exist to accomplish this[10]. However in order to off-load these resources, the mobile device must make use of an appropriate data connection to the Cloud, which due to the connectivity issues mentioned previously, may have a potentially negative effect on power conservation. In addition, creating a connection to the cloud instantly requires further considerations for privacy, security, and reliability; all of which are coupled with increased energy usage[10] Therefore the primary factor which must be taken into account, prior to augmentation of resources by the cloud, is the cost in energy required during transfer, versus the cost of energy consumption upon the device itself.

3. Energy Consumption and MCC

Due to the limited life of power inherent to mobile devices, optimisation of a device's resources and in turn its power consumption allows for maximum usage of the device. The constrained nature of mobile devices has resulted in a body of work which analyses, models and optimises energy consumption for these devices. Cloud Computing, which is dependent upon a fixed power source has been the focus of some work in energy consumption for data centres and networking. Whilst work which analyses energy usage from the MCC perspective (sometimes referred to as: green mobile cloud) has also seen some focus. There is a current push for various strategies which enhance battery life via offloading work to cloud computing environments. The authors in[11] suggest that energy can be saved in the right context, but only for certain tasks. A method of only offloading tasks when the energy consumption via WIFI transfer is efficient, is presented in[12]. Whilst another model for determining whether offloading this computation from mobile devices to cloud are presented in[13]. Sometimes, code is divided up with some executed locally and others executed remotely. A tool which determines which code is to be executed locally and which code is to be executed remotely at compile time, is presented in[14]. The authors in[15] evaluate the effect of offloading resource intensive applications to the cloud, which they call "Energy-as-a-Service", in line with typical cloud service naming conventions. They show that by offloading multimedia services they can gain between 30% to 70% power savings.

In the context of receiving resources from the cloud, Energy consumption in the context of media streaming is the focus in[16] where the authors propose a model which examines the cost of streaming media and then applies inventory theory to decrease this consumption by 10%. This is accomplished through efficient buffering in line with the cellular devices power functionalities. The analysis of energy consumption during network activity is highly relevant with the advent of cloud computing services. The authors in[17] introduce a method which improves energy efficiency by improving the QoS for real-time applications and therefore reduce failures and retransmits etc. Through their solution, power consumption savings of approximately 50% can be seen. An analysis of the energy consumption of cloud-based services on mobile devices in relation to cellular data transfer is presented in[18]. The authors present a solution which creates more efficient use of energy consumption for applications which regularly poll cloud services and therefore cause the cellular interface to spend minimal amount of time low power mode.

Sometimes it is also necessary to consider energy consumption on the Cloud level, as data centres are power hungry so in order to economise on cloud computing it is necessary to ensure efficient operation of hardware. In the context of network modelling and simulation for energy usage within mobile devices, the combination of externally hosted, distributed systems is highly relevant. The energy consumption of high-capacity routers and switches are modelled in[19] whilst an energy model of single, green router device is presented in[20], and a profiling method for general network level power optimisation is introduced in[21].

Energy is of particular importance here, as the end goal of MCC is often the offloading of resources from the mobile device to the cloud in order to optimise resource usage. Therefore in order to determine the exact extent of resource savings, this section has highlighted the need for modelling computational resources on both mobile and cloud devices and the need for this optimisation for an effective mobile cloud.

4. Proposal - User Profiling for Green MCC

A large bulk of work is already available which analyses and models power consumption on mobile devices, some on data-centres and distributed computing; and a minority on the effects of combining the two. Finding an equilibrium between using energy intensive networking interfaces and local processing is vital to ensure such the MCC paradigm is economically for all concerned. A variety of work is available which models different energy usage on the atmoic mobile node, in the combined network and with specific use cases such as execution offloading. In the context of mobile devices, some types of hardware will typically cause more drain than others such as RF interfaces and Displays. However, as end-users will use their devices in a variety of different ways, it could be argued that by a further analysis of a user's activity a profile could be generated to determine their power usage according to interaction, component usage etc. for each application. This would pave the way for optimisation of MCC by allowing both parties to determine if the profile was suitable for offloading.

The authors in[22] model user activity on the high level, in contrast to the most common models which inspect hardware usage per component or simply, the power source. It is proposed that this is taken further into building a model of that user's activity so that information can be gained about their energy usage and therefore determine if resource augmentation is efficient or not. This will then provide predictive profile information to a negotiation service which will determine the how appropriate

The rest of this section details the proposal for user/application-profiling system for mobile devices to enable more effective resource augmentation from remote cloud resources.

4.1. System Components

This section lists the various components required to develop an energy profile of the end-user. A conceptualisation of the component interaction is presented in figure 1.

4.1.1. Data Logger

In order to build up a profile of energy consumption, a wide variety of data must be logged. A data logging service will be active on the device which will monitor the following:

- Application Usage
- Hardware Component Usage
- Network Activity
- Power source drain

Time series data will be logged for each component and will form links between the application's usage of individual hardware components and therefore its overall energy drain. This information is then stored in an historical database. As mobile devices vary in operating system and hardware etc. the exact method of logging will have to be determined according to device and use case. Empirical testing will help to determine an efficient method for logging so as to minimise overhead

4.1.2. Profiler

After collecting data on many application usages, these individual records will be built up to produce a set of usage profiles for each application. Therefore allowing a prediction of the potential energy and resource consumption of the application. Depending upon the final chosen method of profiling, this module may be executed in a remote environment in order to save resources on the constrained mobile device. In order to determine the exact method of profiling, statistical techniques will be leveraged for accurate prediction. The exact technique will be chosen through experimental analysis in order to strike a balance between accuracy and energy efficiency (on the end user device). This component may also be moved to an external system (such as the cloud) or process historical data when the device is plugged in so as to economise on power consumption.

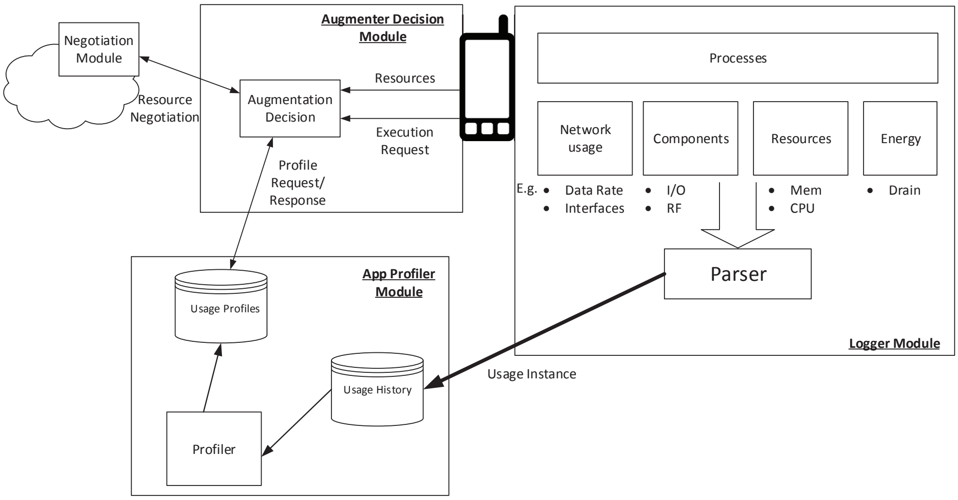

Fig. 1. System Structure and Component Interaction

4.1.3. Augmenter Decision

When a need for augmentation of resources is requested/required, the augmenter will assess the current resources available upon the device, including the available battery life. It will then check the profile history and current state of the network connection in order to predict if augmenting resources is beneficial or not. If there is a need for augmentation then the request will be passed to the available CSP(s).

4.1.4. Negotiation Module

The augmenter decision module must also negotiate with a companion model from the cloud provider. The mobile phone client will indicate the price at which it is affordable to upload the resources and if the cloud module agrees then the augmentation will occur. Such a process is less necessary for traditionally hosted cloud platforms with less constrained resources, but for platforms such as cloudlets this will be particularly useful as they may need to negotiate with multiple clients and decide quickly to maximise power consumption and revenue. Sometimes a client may only be within proximity to the cloudlet for a short amount of time which reiterates the need for a quick and automated decision.

4.2. Analysis and Impact

The proposed platform has a number of intended beneficiaries.The end user of a mobile device has the potential to benefit the most,through enhancing the functionality of the mobile device by enabling resource augmentation in an energy efficient and cost effective way. Cloud service providers can also benefit by providing a more effective method of providing resource off loading to mobile devices. In particular, providers of cloudlets will benefit greater, as these systems may tend to be more constrained than a conventional cloud. As there will be competition between mobile clients, it is highly beneficial to be able negotiate usage which is economically suitable for both parties. Particularly if the cloudlet is operating in a public area where resources will need to be provisioned quickly. Other possible benefits of the system design include the ability to optimise MCC in terms of cost and energy in a dynamic way, allowing the efficiency to adapt for multiple users. The system may also be tailored to a wide range of use-cases, devices and cloud models. For example, its application to ad-hoc clouds could enable more efficient usage for this highly energy constrained cloud.

A number of potential challenges to the development and introduction of the proposed system have been provisionally identified. Firstly, there is potential for an excessive overhead on the mobile device during both the logging and profiling stages. As the system's primary goal is to economise on energy consumption, overhead must be kept to a bare-minimum so as to not put any further strain on the device. The most appropriate logging method will have to be tested through empirical evaluation. The application profiling module is likely to be considerably resource intensive due to the various calculations which will need to be performed and then evaluation of the models. This is likely infeasible to do whilst the device is mobile and therefore will likely occur when device is attached to a fixed power source or when resources may be augmented by a less constrained device.

During the application profiling, it will be necessary to find a way to decouple the data when multiple applications are executing so as to be able to accurately build models. Another issue is in the potential for misuse by end users. Openness of the code and protocol could cause some users to subvert the system by fraudulently claiming that resource use would be more expensive than it in fact would be and therefore claim cheap computation at the expense of the provider. The final foreseeable challenge is the potential for profile creep, where by a users' habits may change over time and therefore models may not accurately predict energy usage. This will require mitigation through periodic evaluation of the models where they may be updated as necessary.

4.3. Scenario

A brief scenario is presented to highlight the process and benefits involved with the system. In this scenario, a user requires resource augmentation from a cloudlet in a metropolitan area. Consisting of the following steps:

1. A smart mobile device user performs resource heavy predictive analysis whilst commuting to work to help make key financial decisions. The exact extent of processing will vary day to day but is directly related to the variables input by the user.
2. The resource intensive application has it a threshold for resource usage on the device which causes the logging module to being profiling its usage.
3. An historical set of profiles is built up surrounding the application, which is then used by statistical analysis to build predictive models for future energy consumption.
4. Once the models have been built and evaluated (potentially on a less resource constrained device), they are stored on the mobile device for later uploading.
5. Whilst commuting, the end user's device receives an announcement from a local cloudlet, offering resource augmentation. During execution of the resource intensive application, the profiler flags potentially excessive energy consumption.
6. The smart media device uploads the potential usage cost to the cloudlet provider. The cloudlet agrees and the transaction begins.
7. The results of the processing are returned to the device and the user continues with their commute.

5. Conclusion

Mobile Cloud Computing is an emerging field which has the potential to provide huge performance increases and increased energy optimisation to mobile devices through augmentation of resources. However, in order for such a symbiotic relationship to be economically viable, the balance must be found between the cost of using an energy intensive communications interface to offload and retrieve the data or merely using the device's own resources. To overcome this user, this paper presented a system architecture for profiling an individual user's energy usage per application, in order to build predictive models for future consumption and therefore determine when it was exactly economically viable to augment the resources. Future work will expand this system in a number of areas: Firstly through the development of the efficient logging mechanism, although work is already available in this area to a degree. Second, an accurate profile will be developed and tested on a multitude of devices, hardware types and applications. Finally the negotiation algorithms will be tuned for appropriate usage. A proof-of-concept will showcase the architecture and help to enable future work in providing energy efficient green mobile cloud computing using the CloudExp tool[23].

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